Volume 15 DECEMBER, 1945 Number 3

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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The subscription price of the *Journal of Sedimentary Petrology* is $3.00 per year prepaid to addresses in the United States.

Single numbers, $1.50 each.

Postage is charged extra for all other countries: 40 cents on annual subscriptions (total $3.40).

The *Journal* will furnish reprints at cost. Orders should accompany corrected galley proof.

Communications about the *Journal*, subscriptions, rates, memberships, change of address, advertising and non-receipt of preceding numbers should be addressed to Society of Economic Paleontologists and Mineralogists, P.O. Box 979, Tulsa, Oklahoma. Claims for non-receipt of preceding numbers must be sent in within three months of the date of publication in order to be filled gratis.

Communications in regard to manuscripts or purely editorial matters should be addressed to W. H. Twenhofel, Editor, University of Wisconsin, Madison, Wisconsin.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN, U.S.A.

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 15, NO. 3, PP. 75–83
FIGS. 1–4, TABLE 1, DECEMBER, 1945

SEDIMENTARY VARIATION: SOME NEW FACTS AND THEORIES

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ABSTRACT

Efficient statistics suitable for the estimation of mineralogical variation and covariation are indicated. Certain of the variational and covariational characters of sediments are exemplified and discussed, and tentative theories developed to account for them.

The petrological characters of sediments do not change lawlessly from place to place. Many, indeed, are demonstrably systematic in their variation, and some probably never acquire true randomness in the strict statistical sense. This is to be expected, for the frequent local predominance of highly selective oligarchies within the sedimentary cycle is well known to be potentially operative at most stages; and such influences must often preclude the balance of multitudinous causes necessary for the administration of a state of chance.

Both mineralogical attributes and mineralogical variables are prone to systematization within horizons and restricted vertical sequences. These habits characterize sediments as vividly as any other peculiarity, and their interpretative value is often very high. Their study is consequently important,—a vital progenitor of that all-embracing theory of sedimentation which is surely the main goal of sedimentary petrology.

Doubtless the most striking aspect of sedimentary variation lies in the bewildering fluctuations of mineralogical proportions. These normally operate both from horizon to horizon and from place to place within the same horizon. In contrast, the least striking aspect of sedimentary variation probably lies in the subtle covariation which often links mineralogical attributes with mineralogical variables. It is the purpose of the present paper to deal briefly with certain aspects of these two extremes.

INTRAFORMATIONAL VARIATION IN MINERALOGICAL PROPORTIONS

Technique. The true mean proportion of a mineralogical constituent of an extensive sedimentary horizon or formation can only be estimated. Statistical methods, based on the theory of sampling, are therefore necessary. The best estimate is obtained from number-percentage determinations (p_1, p_2, $\cdots$, p_c, say) using large random samples (>1000 grains in each). The arithmetic mean of these

$$\left(\frac{\sum (p)}{c}\% ; = p_m\% \text{ say}\right)$$

will then be the best estimate, and its uncertainty penumbra will be given by its standard error,

$$\pm\sqrt{\frac{\sum (p-p_m)^2}{c(c-1)}}\%.$$

In the same way, the true "average geological variation" occurring within an horizon or formation can, at the best, only be estimated. It is most conveniently considered as the standard deviation of the sampling distribution adopted,—a statistic calculated in any case. The closest estimate obtainable from c percentages is

$$\pm\sqrt{\frac{\sum (p-p_m)^2}{c-1}}\%,$$

—the "total standard error of the forma-

tion" ('SE_f'), or the "total standard error of the horizon" ('SE_h'). This will be affected by the sample-sizes underlying the individual percentages. Unfortunately, the total number of grains counted per sample ($n_1, n_2, \cdots, n_c$, say) cannot be rigidly standardised. The most convenient solu-

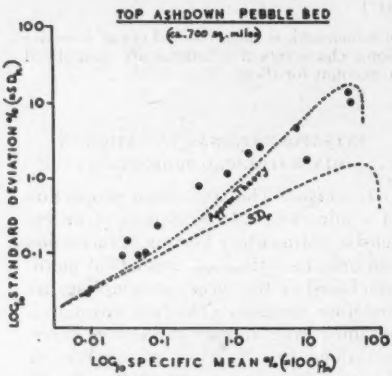

FIG. 1. The species plotted are respectively ceylonite, clinozoisite+fluor+glaucophane +corundum +sphene +zoisite, sillimanite, lepidote, monazite, brookite, kyanite, apatite, staurolite, garnet, anatase, tourmaline, rutile, zircon, black iron ore+leucoxene, in order of increasing mean per cent.

tion appears to lie in comparing all total standard errors with the corresponding estimates of what they would have been had the fluctuations in mineralogical proportion been entirely due to chance. The best estimate of such a "unit" standard error is always given by

$$\pm\sqrt{\frac{p_m(100-p_m)}{H}}\ \%,$$

—the "standard error of random sampling," or 'SE_r', —where H is the harmonic mean number of grains per random sample $\frac{c}{\sum(1/n)}$. The ratio $SE_{f.h}/SE_r$, or '$k_{f.}$'$_h$ (Allen, 1944), may then be used as an estimate of the geological variation expressed in terms of the estimated random variation. When the geological variation is significantly greater than the random variation (i.e. when $k_{f.h}>1$, sign.) it may be described as "supernormal"; when the geological variation is significantly less than the random variation ($k_{f.h}<1$, sign.) it may be described as "subnormal" (Yule and Kendall, 1937). This is most conveniently tested by χ^2, using Brandt's and Snedecor's formula for a $2\times n$ contingency table (Fisher, 1944; p. 87). If the actual numbers of grains of the particular species counted per sample are $g_1, g_2, \cdots, g_c$, then

$$\chi^2=\frac{(\sum n)^2}{\sum g\cdot\sum(n-g)}\cdot\left[\sum\left(\frac{g^2}{n}\right)-\frac{(\sum g)^2}{\sum n}\right].$$

Data. Several sets of sedimentary data have been analysed in this way. They relate to the vertical sequencies of the London Clay, Bagshot and Barton Beds (Eocene) of the Alum and Whitecliff Bays in the Isle of Wight (Miss P.S. Walder's unpublished data); to certain modern sediments in the Bosque River (Rittenhouse's data, 1944); and to the Lower Wealden horizons of the Top Ashdown Pebble Bed and Top 4″–6″ Ashdown Sandstone (Lower Cretaceous) in the Weald of Sussex, Kent and Surrey (Allen, 1938, 1941). In all cases the estimates of geological variation (specific and varietal) increase in magnitude with increasing mean mineral abundance. The correlations, which are significant, are exemplified in figs. 1 and 2. For allogenic species, the general form of the central trend (constructed by "least squares" in the ordinary way) is remarkably constant. This exhibits practical coincidence with the appropriate random sampling distribution (i.e., $k\gg1$ sign.) for the lower values of p_m(<0.01%), and increasing divergence from it for the higher values less than about 50% ($k>1$ sign.; and $k_{f.h}\propto p_m$).

General Deductions. Two general conclusions regarding the nature of the geo-

logical universes sampled may be drawn from the above statistics.

First, providing that the sampling was really simple, it is reasonably certain that the significantly supernormal estimates of *specific* variation ($k>1$, sign.) came from "patchy" universes. Values of $SE_{f,h}$ drawn simply from such a source must generally give k's greater than unity, for each is inevitably compounded of two parts,—one due to the ordinary random sampling fluctuations (SE_r) of the observed values ($p_1, p_2, \cdots, p_c$) about the true overall mean (p_m), and one ('SE_p' say) due to fluctuations of the "patch" values about the true overall mean. These component errors are related to the total standard error by

$$SE_{f,h}=\sqrt{SE_p{}^2+SE_r{}^2}$$

if large samples are utilized. Patchy universes, moreover, are well known to occur in sedimentary deposits. This conclusion was corroborated, in the case of the Wealden horizons, by close sampling (Allen, 1944).

Secondly, it may be deduced that the true variation is systematized in some way. Why, for instance, should the specific variation occurring within the sediments tend to constitute a particular function of mean specific abundance?

Theoretical Considerations. The mechanism which produced the peculiar type of variation was certainly a geological one, for while the particular $p_m-SE_{f,h}$ relation always appears to be operative in naturally disposed sediments, it has never been found to exist within homogenised material (Allen and Walder, 1945). Secondly, the mechanism was incompletely species-selective.

Theoretically, specific patchiness may arise in three distinct ways, viz. by local additions, by local subtractions, and by combined local additions and subtractions of specific material. Local additions of material may be effected through variations at source (differences of mineral assemblage, specific size, etc.), by current-sorting, alteration, authigenesis, and grain-breakage. There is, however, no apparent reason why differences at source, alteration, or authigenesis should ever necessarily generate high $p_m-SE_{f,h}$ correlations, and neither of these factors is likely to have been a prime cause in the Bosque River. Basin-currents also fail, because they are unlikely to have possessed widespread predilections of a purely additive nature; and grain-breakage is equally impotent as a primary cause for mathematical reasons—even when considered to be strictly localized. Authigenesis too (whether pre- or post-depositional), is unsatisfactory because of its notorious specific prejudices. Finally, theoretical investigation of "ideal" environments (carried out in the manner indicated later) reveals that, even if some form of $p_m-SE_{f,h}$ correlation where to arise from a process fundamentally additive in character, it would be far more likely to belong to a type quite different from that observed.

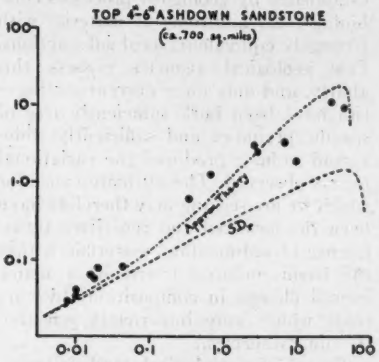

FIG. 2. The species plotted are respectively ceylonite, lepidote and clinozoisite + fluor +glaucophane+stilpnomelane (equal), monazite, kyanite, sillimanite, brookite, staurolite, apatite, garnet, anatase, tourmaline, rutile, zircon, black iron ore+leucoxene, in order of increasing mean per cent.

Again, local subtractions of specific material might be effected through variations at source, current-sorting, mineralogical alteration and mineralogical loss.

But mineralogical loss may be passed over for the same reasons as alteration and authigenesis, and examination of hypothetical environments reveals that repetitive local subtraction would probably lead to $p_m - SE_{f.h}$ relationships quite unlike those discovered in nature.

The observed cases of sedimentary patchiness may therefore have become established by geological processes combining local additions of material with (?roughly equivalent) local subtractions. Few geological agencies possess this ability, and only one—current-sorting—can have been both sufficiently free of specific prejudice and sufficiently widespread to have produced the variational trends observed. The ultimate cause for which we are seeking may therefore have been the localized and repetitive transference of sedimentary materials within the basin, induced (?without a major overall change in composition) by currents which were imperfectly selective for mineral species.

The chief petrological tendencies inherent in the above conclusion may be deduced approximately and compared with the facts. Consider an "ideal" basin of deposition dominated by specifically selective current-action. Imagine that a statistically homogeneous sediment comprising h mineral species in the following arithmetic mean proportions—$p_{m1}\%$, $p_{m2}\%$, $\cdots$, $p_{mh}\%$,—becomes spread across it. Let a certain locality contain N sand-grains distributed in the above proportions so that there are x_1 grains of the first species, x_2 of the second, $\cdots$, and x_h of the hth. The "local" constitution may then be considered as approaching

$$100\left(\frac{x_1}{N}\right), 100\left(\frac{x_2}{N}\right), \cdots, 100\left(\frac{x_h}{N}\right).\ \%$$

Now suppose than an "ideal" current which is selective for mineral species acts upon this locality and removes y_1 grains of the first species. The "local" constitution will then approach

$$100\left(\frac{x_1-y_1}{N-y_1}\right), 100\left(\frac{x_2}{N-y_1}\right), \cdots, 100\left(\frac{x_h}{N-y_1}\right).\ \%$$

That is to say, the proportion of the first species will be decreased to

$$\left[\frac{N(x_1-y_1)}{x_1(N-y_1)}\right] p_{m1}\%,$$

while the proportions of all the remainder will be raised to

$$\left(\frac{N}{N-y_1}\right) p_m\%,$$

i.e., *by a constant fraction of themselves.*

Now suppose that the same material (or an equal amount of similar material) is returned to the sediment elsewhere. In the new locality another change of constitution will likewise occur, but this time the proportion of the first species will be augmented, and the proportion of the remainder will be depressed,—*again by a constant fraction of themselves.* If the environment were "perfect" and there were N grains in the new locality, the former would be increased to

$$\left[\frac{N(x_1+y_1)}{x_1(N+y_1)}\right] p_{m1}\%,$$

the latter depressed to

$$\left(\frac{N}{N+y_1}\right) p_m\%.$$

Repetition of such a dual process (in differing degrees) on different species in equal-sized localities will initiate a state of patchiness and a gradual onset of systematization. Hence, though (in the absence of breakage) the mean overall proportions of the constituents of the sediment will remain unaffected, the mean local proportions will be altered,

and the amounts of specific variation thereby modified. If there are L localities and (again assuming "perfection") each of the species is subtracted in an equal number ($L/2h$) and added in an equal number ($L/2h$) of them, the resulting total variation ($SE_{f,h}$) of any species will change—when H is large (as it must always be)—from SE_r to $\sqrt{SE_{p'}{}^2+SE_r{}^2}$. Consequently, if the actual numbers of grains removed and added locally are $y_1, y_2, \cdots, y_{(L/2h)}$ for the species concerned, and $y_{(L/2h)+1}, y_{(L/2h)+2}, \cdots, y_{L/2}$ for the remaining species, it may be shown that

$$SE_{f,h}=p_m\sqrt{j+\frac{200}{L}\left(\frac{100-2p_m}{p_m{}^2}\right)\sum_{y_1}^{y_{L/2h}}\left[\frac{y^2(N^2+y^2)}{(N^2-y^2)^2}\right]+\frac{100-p_m}{Hp_m}}\ \%,$$

in the "ideal" case, where j is constant for all species and equal to

$$\frac{2}{L}\sum_{y_{L/2h+1}}^{y_{L/2h}} y\,\frac{L}{2h}+1\left[\frac{y^2N^2+y^2}{(N^2-y^2)^2}\right].$$

And this expression embraces the class of functions to which the central trends observed in nature belong.

Accepting the above as support for the "give-and-take" theory, we may attribute the diffuse scattering of the observational data (apart from sampling errors) to obvious geological factors not treated in the over-simplified and highly idealized mathematical approach. The more potent of these will of course normally be initial non-homogeneity of the sediment, inconstancy of "locality" size, non-specific selection, repetitive local selection, variation in current-competence, grain-breakage, alteration, loss, and authigenesis.

Possible Utility. Evidently, in the above equation, when

$$p_m=50\%,\ \left(\frac{100-2p_m}{p_m{}^2}\right)=0.$$

the j-values of a particular sediment may therefore be estimated,—either directly (from that species forming about 50% of the suite, and/or from combinations of species), or by interpolation in the appropriate $p_m-SE_{f,h}$ curve. These statistics appear to have some use in the characterization of sediments.

Since the fractions removed and added locally must always be unknown, exact "expected" curves can never be constructed from the equation. For crude comparative purposes, workable approximations may be derived by assuming either (i) that

$$y=\frac{x}{d}\left(=\frac{p_mN}{100d}\right),$$

where d is constant and $p_m{}^2$ is small compared with d; or (ii) that the summation is equivalent to $jL/2h$. The former has been utilized in the accompanying diagrams.

Approximation and observation often closely correspond. It is possible that this may be due to overall similarities of current-treatment meted out to the various species.

INTRAFORMATIONAL CORRELATIONS BETWEEN MINERALOGICAL CHARACTERS

Technique. Mineralogical correlations within sedimentary rocks are most easily detected by visual comparisons of the statistical data. The latter are best presented on maps and scatter diagrams. For instance, the areal distributions of staurolite frequency and the zircon size index (Allen, 1944) in the Top Ashdown Pebble Bed and Top 4″–6″ Ashdown Sandstone horizons conform to closely similar isopleth-patterns, thus raising the possibility that the two characters are linked in some way or other.

The *establishment* of such a correlation is, however, not so simple. In the first place, its magnitude must be estimated quantitatively. When the true regression is linear, this is conveniently carried out in terms of the correlation coefficient

('r'). In testing the significance of this statistic, P-values* may be obtained by the t-test, using Fisher's modification (Fisher, 1944, p. 188), viz.

$$t=\frac{r\sqrt{v-2}}{\sqrt{1-r^2}},$$

where v is the number of pairs of variates (observations).

The examination of correlations involving up to 102 pairs of observations is greatly simplified by Table V.A. of the same author (Fisher, p. 204). From this, P-values may be read off directly. When the regression is not linear, the correlation ratio ('η') may be used.

Differences between similar types of correlation (as from one horizon to another) are best examined by transforming the statistics into their corresponding z-values (Fisher, pp. 192–199, and Table V.B., p. 205), and testing these instead.

Data. Statistically significant correlations between mineralogical characters of sediments appear to be of general occurrence. Probably the most frequent—and certainly the most evident—is that linking specific and varietal frequencies with grain size. In all the rocks where it is known to occur, this particular relationship is confined to a small number of mineral species. It may vary in character and magnitude from one species to another.

A particularly striking example is afforded by the upper Ashdown (Lower Wealden) strata of Sussex, Kent and Surrey. Within the Top Ashdown Pebble Bed, the areal distributions of staurolite frequency, kyanite frequency, sillimanite frequency, garnet frequency, apatite frequency and the zircon size index yield

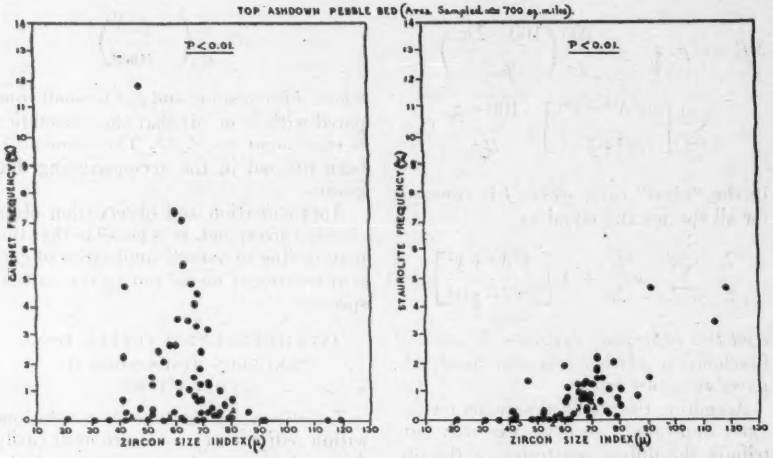

FIG. 3. A highly significant curvilinear correlation between allogenic mineralogical frequency and allogenic particle size. (Areal distributions within an extensive horizon usually 2–4 inches in thickness.)

FIG. 4. A highly significant straight-line correlation of the same type as shown in fig. 3. The departure from straight line regression is insignificant (i.e., P, from F-test, <0.05). The correlation coefficient is therefore used. $r=0.715\pm0.0874$; whence $t=8.181$, giving $P<10^{-6}$.

* *A value of P being the estimated probability that the particular r-value might have arisen by random sampling from a corresponding population of uncorrelated individuals (pairs of observations).*

closely similar isopleth patterns. While staurolite, kyanite and sillimanite appear to be most abundant in the coarser facies, garnet and apatite attain their maxima in the intermediate grades and decrease in the coarser and finer grades. The garnet frequency-zircon size index and apatite frequency-zircon size index correlations are curvilinear (see e.g. fig. 3), while the staurolite, kyanite and sillimanite frequency-zircon size index correlations are linear (see e.g. fig. 4). All more staurolite, kyanite and sillimanite, and less garnet and apatite than those from the finer Top 4″–6″ Ashdown Sandstone. The gist of this is summarised in the accompanying table.

The regression equations permit rough forecasts to be made of the proportions of correlated species present in facies of any known grade. In general, such forecasts should be reliable for both the horizontal and vertical dimensions of a formation *so long as no major genetic or distributive*

TABLE 1

Horizon	Arithmetic Mean Proportion (%)					Arithmetic Mean Zircon Size Index (μ)
	Staur.	Kyan.	Sillim.	Garn.	Apat.	
Top Ashdown Pebble Bed	0.79 ±0.106	0.085 ±0.0204	0.029 ±0.0085	1.50 ±0.193	0.31 ±0.0993	64.1 ±2.07
Top 4″-6″ Ashdown Sandstone	0.36 ±0.0751	0.018 ±0.0071	0.019 ±0.0092	2.60 ±0.374	0.73 ±0.164	53.8 ±2.00
P for upward diff. observed	<0.001	<0.01	0.43–0.42*	<0.01	<0.03	<0.001
Nature of upw. diff. ob.	+	+	+*	–	–	
Nature of upw. diff. expected	+	+	+	–	–	

* Difference therefore not significant statistically.

five correlational statistics are significant ($P < 0.05$) and are therefore considered to indicate the presence of real correlations in the rocks sampled. Closely similar data (involving the same specific minority) were obtained from the arbitrary Top 4″–6″ Ashdown Sandstone horizon.

Analysis by means of the *s*-test revealed that corresponding correlations in the two horizons do not differ significantly in degree. Further, the application of regression analysis to the entire information discloses that the horizontal changes in mean proportion of the correlated species can be "accounted for" by the differences in grade (zircon size index). As expected, the samples from the coarser Top Ashdown Pebble Bed contained *change occurs therein.* This approach is therefore likely to be useful as a critical test of unity within a "petrographic province" or a "petrographic episode."

Partial correlations between mineralogical characters are frequently resolvable in terms of grade size as the fundamental variable. Unfortunately, this is not usually sufficient to elucidate the genetic or environmental problems under investigation, for grade size may constitute a reflection of one, or more than one, of many diverse factors, or even be itself genetically fundamental (see below).

Possible Interpretation of Frequency-Grade Size Correlations. The interpretation of these correlations therefore turns

on the difficult question of postdepositional alteration, loss and authigenesis. When it is clear that these processes were small in extent, then the competence of the transporting currents must be considered as a potential major cause. But when postdepositional modification was extensive, then such factors as postdepositional porosity must also be considered.

The problem may be restated as follows: Why should the frequencies of a few allogenic species vary systematically in harmony with grade size, whereas the majority change in proportion quite haphazardly, irrespective of grade? The answer to the former problem must lie almost certainly in either (1) selective "panning" within the basin (carried out according to grade size and facilitated, for example, by slow sedimentation combined with long-continued current-action) following transport by currents having unspecified ranges of competence; or (2) restricted transport by currents able to shift only certain fairly well-defined ranges of particle size,—followed or not followed by selective "panning."

If selective "panning" were the main cause, then the differences in correlational behaviour would probably be small. The order of magnitude of the grades at which the correlated species reached their maximum frequencies would indeed (if recognizable), be likely to correspond more or less closely with the order of specific mean size normally observed in single samples. If restricted transport were the main cause, on the other hand, the behaviour of the correlates might differ widely, and the order of magnitude of the grades at which they attained their maximum frequencies would not necessarily correspond with the size-order of single samples. Only those which travelled in company or in drainage systems having similar degrees of competence would, if subsequently "panned" according to size, also tend to exhibit the normal size-order of single samples. On the other hand, those species which travelled in drainage systems having dissimilar degrees of competence would be expected to show widely dissimilar correlations, and thus to reach their maximum frequencies in facies of very different grades. All but the most thorough forms of "panning" would doubtless fail to obliterate this.

Similarly, the lack of correlation in the remaining species may be expected to have arisen through transport by currents covering relatively wide ranges of competence. "Panning" (at least according to grade size) is unlikely to have followed this.

Summary of Interpretative Criteria Suggested. The tentative conclusions reached above may be summarised as follows:

(1) *Species Showing Significant and Closely Similar Grade Size-Frequency Correlations:*—Probably all transported by currents of similar competence. (a) Those reaching maximum frequencies in grades whose order of magnitude resembles that of single samples, probably travelled together in currents having widest possible range of competence. (b) Those for which the latter size-order does not hold probably travelled in currents of restricted but similar ranges of competence,—i.e. almost certainly together. (Consistently, the few observed minerals of this type belong to the less common species, and are genetically the most nearly related of the correlates.)

(2) *Species Showing Insignificant but Very Different Grade Size-Frequency Correlations, and Usually Reaching Their Maximum Frequencies in Facies of Widely Different Grades Whose Order of Magnitude is Quite Unlike That of Single Samples:*—Probably transported by currents having different and restricted ranges of competence,—i.e. involving a strong likelihood of carriage in distinct drainage systems. (Consistently, the observed minerals of this type mostly belong to the less abundant species, and are genetically the more distantly related of the correlates.)

(3) *Species Showing Insignificant Grade Size-Frequency Correlations.* Probably all transported by currents covering a rela-

tively wide range of competence, and not subjected to extensive "panning." (Consistently, the uncorrelated species are usually observed to comprise the more ubiquitous minerals of ordinary source-complexes.)

The recognition of and differentiation between degrees of "sorting" and mutual or separate transport, are surely among the next major objectives of petrological research. If, in attempting to indicate a new approach, these reflections stimulate some discussion and controversy directed towards that end, then the main purpose of this paper will have been fulfilled.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 15, NO. 3, PP. 84–87
PL. 1., DECEMBER, 1945

TRANSPORTATION OF MARINE BEACH SAND BY FLOTATION[1]

K. O. EMERY
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ABSTRACT

Floating sand has been abundantly reported from streams, lakes, and estuaries, but its frequent occurrence on marine beaches has received little attention. On beaches, flotation results in transportation for only a few yards, but the selective sorting by size, angularity, and mineralogy of the sand grains may be of some geological interest.

GENERAL

The presence of patches of sand and sometimes even of stones floating on the surface of water has stirred the interest of many observers because of the incongruity of material of high specific gravity floating on a liquid of lower specific gravity. A score of observations have been published in the form of short notes. These reports were summarized by McKelvey (1941) who also gave an excellent discussion of surface tension, the means by which the particles are supported.

Sand may be found floating on water of streams, lakes, estuaries, and marine beaches. Even more often it may be seen floating on street puddles after rains. Of the natural environments, marine beaches fronting the open ocean have been practically neglected in previous reports, though floating sand is commonly present.

MARINE BEACH ENVIRONMENT

Floating sand has been noted by the writer in four different portions of open marine beaches: large ponds on the backslope, tidepools, rills, and at the edge of advancing waves.

Some beaches have a profile such that a crest, which is somewhat above high tide, separates the seaward sloping foreshore from a broad gentle blackslope. At the highest tides, the first wave which washes over the crest of the beach initiates a pond and successive waves increase its area and depth. As the water-line of the pond slowly advances, many of the sand grains at the surface are lifted and floated, and they soon collect in patches. If there is a slight breeze, much of the sand floats to the leeward side of the pond. When the tide falls, the water of the pond filters out through the beach and the floating sand is stranded, largely along the highest water-line on the leeward side.

Floating sand is even more common in the quiet tide pools left by a falling tide between large ripple marks and in scoured areas around rocks. Sand surrounding these pools is thoroughly wetted during high tide before the pools are formed, but on exposure to air the sand grains require only a moment to repel the surface film of water, especially during a sunny day. Many of these sand grains are launched at the water-line when a gust of wind causes a slight change of water-level. Additional grains also may be launched from the surface of slumping portions of the pool walls. Small rills of water draining into the pools from higher parts of the beach sometimes contribute a small load of floating sand. The ease with which sand can be set afloat is illustrated by the fact

[1] Contributions from the Scripps Institution of Oceanography, New Series No. 268.

that if a handful of sand from the bottom of the pool is lifted above the water for a moment and then gently immersed, much of the surface layer floats away. The floating sand soon collects in elongate patches parallel to the water-line (pl. 1, fig. 1). Usually these patches drift toward the middle of the pool and become more or less circular (pl. 1, fig. 2). As the tide falls, the water in the pools seeps out and the patches of sand are stranded on the bottom and sides of the pools, often intact and in distinctive patterns.

Floating sand may also be found in rills of water running down the beach slope. While the rills consist partly of water draining from intergranular spaces, for the most part they return seaward part of the water carried up the beach by waves. On the surface of the water occasional separate sand grains may be seen afloat. So far as the writer can determine, all this floating sand sinks when it reaches the rough water of the next advancing wave. It then is deposited or joins the sand being carried by saltation or in suspension. Since even sharp-crested ripples are usually sufficient to wet and thus to sink floating sand, it is very unlikely that floating sand from rills of an open marine beach ever passes the breaker zone.

An additional type of sand flotation was described for lake beaches by O. F. Evans (1938b) and this is also present on nearly all marine beaches. As a wave advances over a beach, its edge supports and carries a narrow band of floating sand which is deposited as a swash mark when the wave reaches its highest level and then recedes and partly sinks into the beach. Especially evident on marine beaches is a zone where the sand is covered by a very thin but smooth glassy layer of water left by a wave (pl. 1, fig. 3). Just landward of the glassy surface, the sand, though still wet to the touch, presents a dull granular surface, and there the grains apparently have repelled part of their surface film. Because the top of the sand grains is dry only in the zone having a dull granular surface, grains are picked up by advancing waves and swash marks can thus be formed only in that zone. Swash marks are formed rarely, if ever, in the zone having a glassy surface.

PETROGRAPHIC CHARACTERISTICS OF FLOATING SAND

Most published accounts give the size of floating sand as medium, coarse, or very coarse. R. T. C. Evans (1900) reported even stones floating from a marine beach. Floating sand collected from a lake and sieved by O. F. Evans (1938a) proved to be coarser than the beach sand from which it was believed to have been derived. It had a median diameter of 0.50 mm. as compared to 0.33 mm. for the samples collected from the lake beaches, thus indicating some selection. Floating sand collected from a tide-pool (pl. 1, fig. 2), however, had the same median diameter as that from the pool walls, 0.173 mm.

Simonds (1896) and others report that angular grains float much better than round ones. In accordance, flat angular shell fragments and mica flakes are frequent components of floating sand on marine beaches. As explained by Coghill and Anderson (1918), the selection of angular grains results from the fact that it is difficult for the surface or miniscus of the water to pass around the sharp edges of angular grains, and thus they tend to remain at the surface of the water. Moreover, the weight of a grain must not bear too large a ratio to its perimeter because the force of gravity must be balanced by the surface tensions. Therefore, large grains do not float as easily as small ones unless they are more angular or flatter.

Microscopic examination of the floating sand and the wall sand from a tide-pool (pl. 1, fig. 2) revealed the presence of a large suite of light and heavy minerals. In the $\frac{1}{4}$ to $\frac{1}{8}$ mm. size grade, biotite flakes constituted 33.5 per cent of the floating sand and only 5.5 per cent of the wall sand. In the $\frac{1}{8}$ to $\frac{1}{16}$ mm. size grade, biotite amounted to 4.5 and 1.0 per cent respectively. Only a few grains of biotite

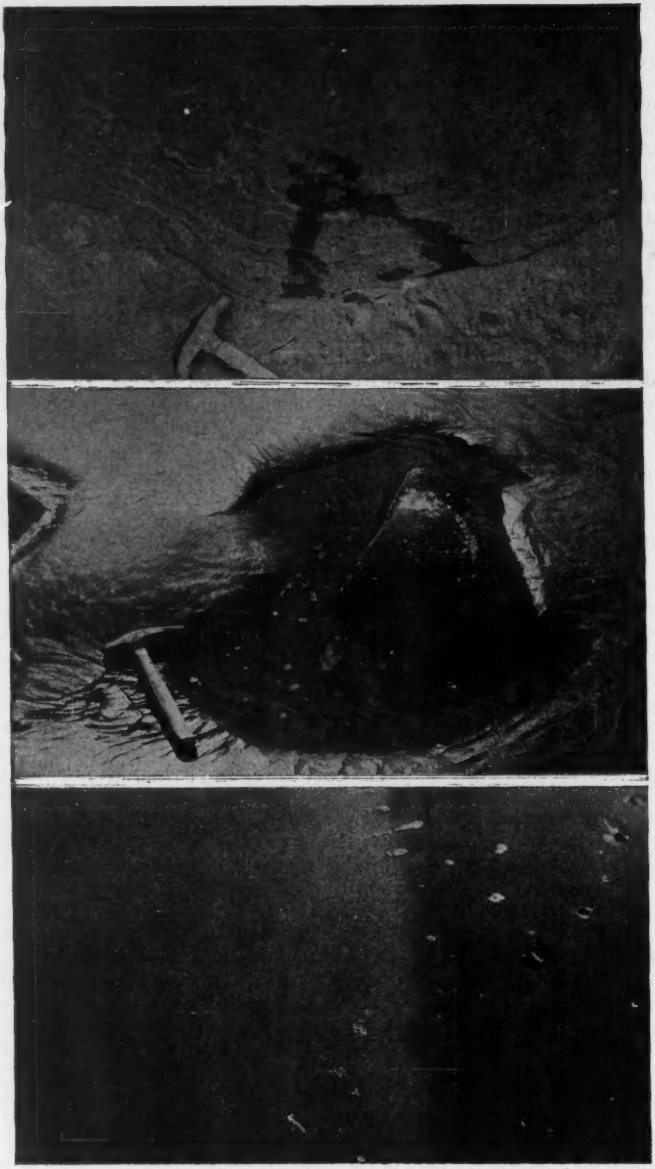

PLATE 1

(See opposite page for legend)

were present in smaller size grades. Although much less abundant, chlorite flakes showed the same relationship. Non-flaky minerals had about equal proportions in the floating and the wall sand after biotite and chlorite were subtracted from the mineral count.

Numerous cursory examinations of swash marks showed them to be similar to the floating sand in that biotite is much more abundant than in the source sand.

GEOLOGICAL SIGNIFICANCE

As pointed out by McKelvey (1941) and others, flotation may result in the transport of large quantities of sand in streams, lakes, and estuaries. While a large quantity of sand is also floated in the marine beach environment, it is rarely transported more than a few yards distance. On the beaches, however, flotation does result in some selection as regards grain size, angularity, and mineralogy so that both the floated and the residual sand can differ from the original sand. Floating sand which is stranded as swash mark has been found in consolidated sandstones and it is possible that patches of sand floating in pools and stranded when the pool drained away also may be preserved.

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PLATE 1. Illustrations of floating sand on beach near Scripps Institution of Oceanography, La Jolla, California.

FIG. 1. Elongate patches of sand floating in a tide-pool parallel to the water line. Dark area is shadow of camera held over pool.

FIG. 2. Roughly circular patches of sand floating in a tide-pool.

FIG. 3. Portion of beach after the seaward retreat of a wave to the right. Scale is given by pebbles one and one-half inches in diameter. Note glassy surface at right which is slowly changing to a dull granular surface. Just after the photograph was made a wave advanced to a position diagonally across both glassy and dull granular zones before it retreated seaward. Sand was floated and a swash mark was formed in the dull granular zone but not in the glassy zone.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 15, No. 3, PP. 88–92
FIGS. 1–3, DECEMBER, 1945

PHOSPHATE DEPOSIT NEAR PRINCETOWN, VICTORIA, AUSTRALIA

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ABSTRACT

A one to three foot bed containing nodules of calcium phosphate exposed in a sea cliff on the south coast of western Victoria, Australia, is described. The bed is Miocene age. The P_2O_5 content of one nodule was found to be 15.08 per cent. The deposit is not considered to have economic importance at the present time.

Location

A small deposit of phosphate at Princetown on the south coast of Western Victoria, outcrops one-half to three-quarters of a mile northwest of the mouth of the Gellibrand River (fig. 1), and just over a quarter of a mile south of the Great Ocean road. It is most conveniently reached over country comprised of Recent sand dunes capping Pleistocene dune limestone, which in turn rests upon Tertiary deposits of Janjukian and Balcombian age.

The phosphate deposit is a nodule bed exposed at the base of steep cliffs

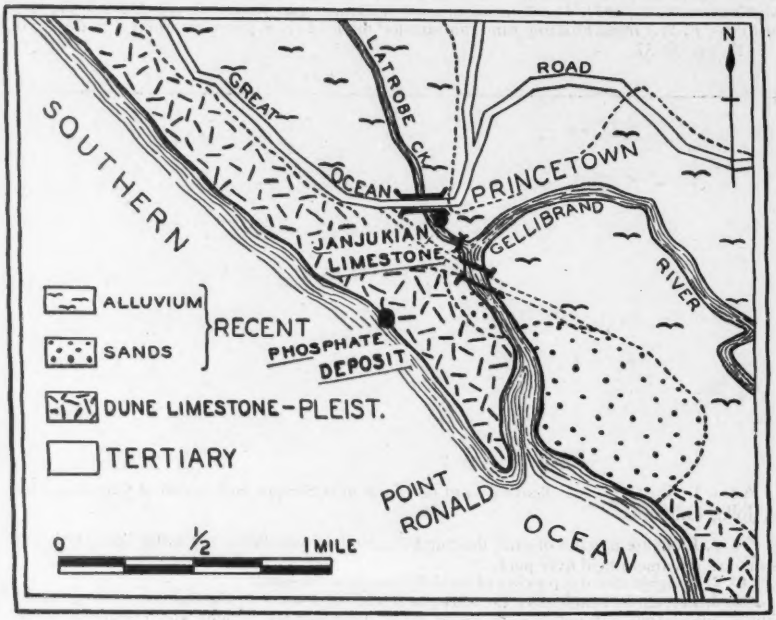

FIG. 1. Map showing location of the phosphate deposit.

(fig. 2) on a very rugged coastline (fig. 2A); it is attacked by high and storm tides where uncovered in the cliff face, but is partially masked by landslides of clay and fallen blocks of Pleistocene dune limestone which have accumulated as cliff débris at the foot of partially overhanging cliffs. These form talus cones which are occasionally 30 to 40 feet high and have contributed largely to making the phosphate deposit difficult of access. Large flat slabs of the nodule bed (fig. 2B) have been broken off the cliff face by storm waves.

Nature and extent

The nodule bed evenly overlies ferruginous gritty sandstone, the top 9 inches of which is occasionally calcareous with few fossils, and is overlain by richly fossiliferous limestone (fig. 2). This is a conformable series of beds dipping in a westerly to northwesterly direction at 2½°. The nodule bed, which can be traced laterally in a N.W. to S.E. direction for approximately 5 chains, ranges in thickness from 1 to 3 feet. The maximum width of the outcrop is 10 feet, and there is no indication how far the deposit continues in a N.E. direction (i.e. into the cliff face).

There exists but a short diastem between the overlying limestone and the nodule bed, since fossils in each are identical. The age assigned to these beds is Janjukian (Miocene) (Baker, 1944). Overlying the limestone in conformable relationship, are marine clays with Janjukian and Balcombian (Miocene) affinities, which are succeeded in a N.W. direction by clays of Balcombian age.

The nodule bed is made up of phosphatic nodules ranging in length from half an inch to one foot, and ferruginous, non-phosphatic casts of corals, pelecypods and gastropods, set in a hard matrix of mixed constituents comparable in part with the material forming the overlying limestone, and in part with that forming the underlying ferruginous gritty sandstone. Species of *Mopsea, Graphularia, Flabellum, Cellepora, Schizellozoon, Chlamys, Spondylus,* echinoids and shark's teeth, the same as those in the limestone above, are

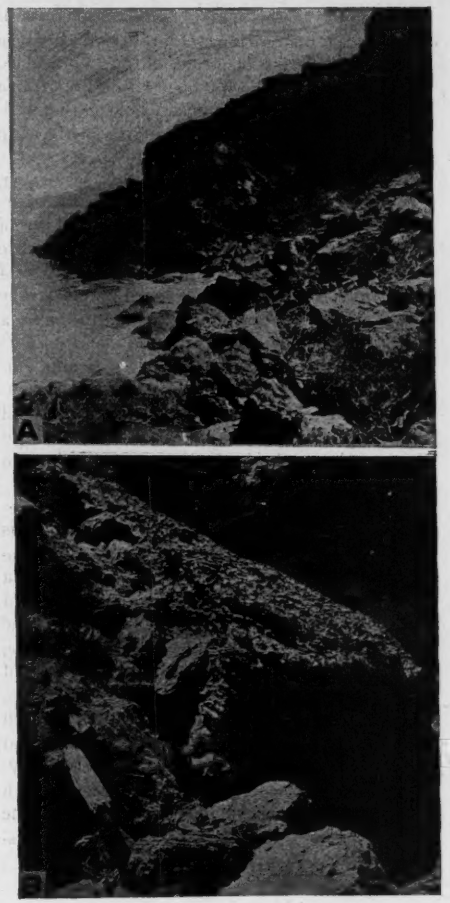

FIG. 2

Description of Plate

A—Rugged character of the coast near the nodule outcrop. Cliffs are 200 feet and over in height; large fallen blocks and talus cones mask parts of the deposit.

B—Large dislodged block from the phosphatic nodule bed, associated with large fallen blocks of Pleistocene dune limestone.

found in this matrix, which also contains large nodosarians, cidaroid spines, worm tracks, casts of species of the Cypraeacea, indeterminate but new species of *Aturia* and *Nautilus*, cetacean bones, and well-rounded, ironstained quartz pebbles up to nearly half an inch across.

The phosphatic nodules are brown, relatively smooth and principally of irregular shapes, often simulating those of nodular flints. A few are ovate, others are elongated and cylindrical and 3 to 4 inches long, ¾ inch in diameter. The cylindrical varieties frequently have a light brown, phosphatic centre surrounded by a zone of quartz grains embedded in ferruginous, argillaceous material containing occasional small fossil bryozoa and foraminifera. The matrix of such portions of these nodules is also somewhat calcareous and phosphatic.

The nodules are mainly dense and fine-grained, consisting chiefly of amorphous calcium phosphate (colophane), but some are of a gritty character, containing a considerable number of quartz grains of variable size and possessing less lime phosphate than is found in the dense, fine-grained phosphatic nodules. Most of the nodules are coated with a thin film of iron oxide. Few nodules have been noted with included macrofossils, and then only as occasional casts of pelecypods. None has yet been observed with crab remains, such as are common in the phosphatic nodules of the Geelong district, Victoria (Keble, 1932, p. 130).

Composition

Partial analyses of (i) a dense, fine-grained nodule and (ii) a sampled portion of the crude rock containing the nodules, but also including the matrix material and certain non-phosphatic nodules, were carried out in order to form some idea of the commercial possibilities of the deposit.

The P_2O_5 content of the dense nodule was found to be 15.08 per cent, a value comparable with the P_2O_5 content of a nodule of concretionary character from Waurn Ponds, which contained 14.99 per cent (Coulson, 1932). The remainder of the nodule consisted principally of calcium carbonate, soluble iron salts and fine clay. The crude rock only contained 3.20 per cent P_2O_5.

Occasional hard, dense patches, in part concretionary, and also two iron-stained bands each up to a foot thick (dark bands in fig. 3) in the limestone overlying the nodule bed, are also phosphatic. Qualitative tests for phosphorus in such portions of the limestone yielded less copious precipitates of yellow ammonium phosphomolybdate than was obtained from the dense nodules in the underlying bed. The phosphatic portions of the Janjukian limestone are associated with encrusting and branching bryozoa, brachiopods, echinoids and pelecypods.

Origin

Wilkinson (1865) regarded the "pebbles" in the nodule bed at Princetown as rolled fragments of fossiliferous Miocene clays, but did not detect their phosphatic character. There is no known deposit in the vicinity from which the phosphatic nodules could have been derived by erosion: this is in contrast with occurrences at Geelong, Victoria, where remanié nodules have been derived from concretionary nodules in limestone (Coulson, 1932). Whereas concretionary phosphatic nodules occur in Miocene limestones which underly a remanié phosphatic nodule bed in the Geelong district, the reverse is found at Princetown, where a limestone with concretionary patches of phosphatic material overlies the bed containing the phosphatic nodules.

The phosphate in the limestone above the nodule bed at Princetown is undoubtedly derived by enrichment along two prominent bedding planes by circulating waters rich in phosphate. The dissolved phosphate may have been derived in part from the underlying nodule bed, but was probably obtained principally from the phosphate content of organisms entombed in the limestone itself. The origin

of the phosphatic nodules is less certain. Bonney (1875) concluded that phosphatic nodules were produced by the phosphatization of various objects on a muddy sea bottom, in the presence of ammonium carbonate and a weak solution of phosphoric acid, and since complex conditions are necessary for this reaction, phosphatic nodules were therefore rare. At Princetown, it appears that the floor of the sea where the nodules were formed was of a gritty character, because they occur in a bed which now rests upon ferruginous gritty sandstone; moreover, the nodule bed contains some of the gritty constituents in its matrix, while the phosphate nodules also sometimes enclose the ingredients of the gritty sandstone.

Twenhofel (1932) recorded the source of the phosphorus in phosphatic nodules as probably being in the shells of organisms and in other organic matter, assumed to have gone into solution or to have been reduced to a colloidal state by the decomposition products developed from abundant organic matter. He thought the fact that nodules on the present sea bottom were merely calcium phosphate cemented portions of sediments in which they occur, was proof that they were formed *in situ*, and not mechanically transported to the places of occurrence. This is borne out by the phosphatic nodules at Princetown, Victoria. Although these nodules do not often enclose fossil shells or casts, the fact

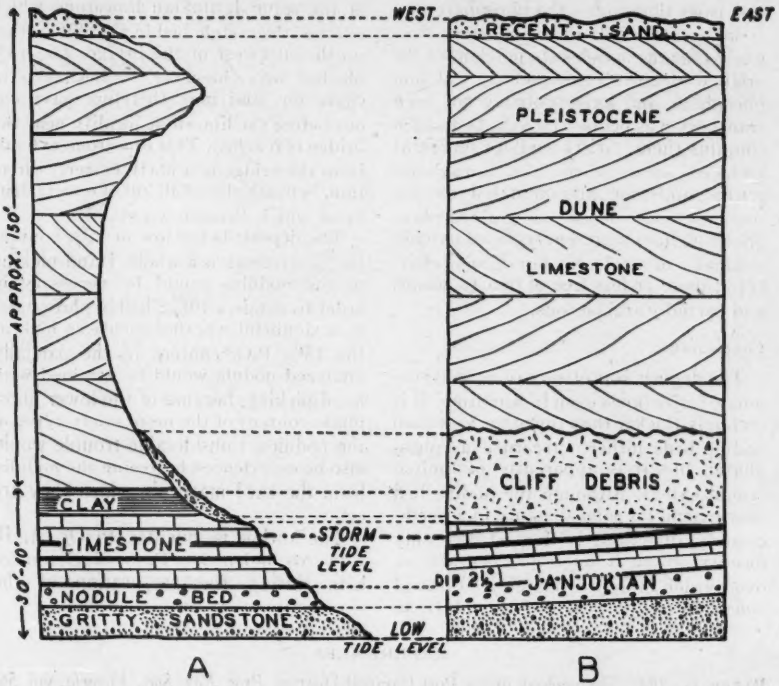

FIG. 3. Sections showing local and stratigraphic positions of the nodule bed in the section exposed in the sea cliff.

that they sometimes enclose matrix material identical with that of the underlying bed, shows that they were formed *in situ*. The absence of fossils from many of the nodules may mean that most shells had been brought into solution along with other organic matter, and that it was from this source the phosphate material originated. It therefore seems most likely that the nodules are portions of the original deposit cemented by calcium phosphate, and have probably not been transported as pebbles into the bed which contains them. Gritty nodules represent replaced areas where the ferruginous gritty sandstone predominated on the sea floor, while dense, fine-grained phosphatic nodules represent replaced patches originally of a calcareo-ferruginous character, more or less free of quartz grains, and partially argillaceous.

Conclusions

The deposit is probably of no real economic importance even in war-time. It is certainly thicker than the other Victorian nodule beds hitherto recorded as phosphatic, but it is apparently of limited lateral extent. Although the nodule bed may extend for some distance in a north-easterly direction, it lies, at the only locality where it outcrops, beneath an overburden of approximately 150 feet of consolidated dune limestone and 15 to 20 feet of Janjukian limestone and marine clays. Boring operations might, however, prove its presence in more favorable positions inland from the coast, because on the south side of the Great Ocean road, near the bridge crossing the Latrobe Creek (fig. 1), further outcrops occur of the same Janjukian limestone which overlies the nodule bed in the cliff section south-southwest of the bridge. The nodule bed may, however, be lenticular in character, and may therefore have cut out before the limestone locality near the bridge is reached. This limestone extends from the bridge in a north easterly direction, beneath the small hill of quartz drift upon which Princetown stands.

The deposit is too low in P_2O_5 content (3.2%) to treat as a whole. Hand-picking of the nodules would be necessary in order to obtain a 10% yield of phosphate. It is doubtful whether yields as high as the 15% P_2O_5 content of the partially analyzed nodule would be attained with hand-picking, because of the lower phosphate content of the more sandy types of the nodules. Considerable trouble would also be experienced in freeing the nodules from the hard matrix in which they are set.

The author is indebted to Dr. A. B. Edwards and to Dr. F. A. Singleton for help during the preparation of the manuscript.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 15, NO. 3, PP. 93–102
FIGS. 1–2, TABLES 1–3, December, 1945

BOTTOM SEDIMENTS OF GREEN LAKE, WISCONSIN

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ABSTRACT

Green Lake is the deepest lake in Wisconsin. Its waters are "hard" and large quantities of calcium carbonate are precipitated. Deposits of this sediment are either in the form of shells of gastropods and pelecypods or small crystalline particles which have no known connection with the shells. Deposition of calcium carbonate extends from the shore to the greatest depth in the lake—237 feet—with the most extensive distribution between depths of 12 and 30 feet.

Sands deposited in the lake are not well sorted. Most characters of the sands were produced in other environments. Only the poor sorting and the stratification are due to lacustrine conditions.

INTRODUCTION

Green Lake (fig. 1) in Green County, Southeastern Wisconsin, is the deepest lake in the state. Its greatest known depth is 237 feet. The deepest part of the lake is near its southwestern end and it is less than 10 feet deep at the outlet on the north side of the northeastern end. The greatest length is 7.7 miles, the greatest width is a little less than 2 miles, and the area is 11.5 square miles. The great depth of the lake assures that it will be among the last of the glacial lakes to become extinct.

Green Lake is surrounded by moderately rolling lands which originally were and to a large extent are still devoted to cultivation, but during the last several decades extensive parts of shore areas have become parts of carefully guarded estates and boy and girl camps, or other quasi-public property.

The depression in which the lake is situated is part of a pre-glacial valley which doubtless was deepened by glacial erosion in some places and in others received glacial deposits. Dams were placed across this valley in several places as the Wisconsin glacier retreated. These formed the depressions in which Green Lake and the adjacent Lake Puckaway are situated. The original valley had about the direction of advance of the Wisconsin glacier and hence the lake has elongation in the same direction. The original valley seems to have been narrow and steep-sided, and, accordingly, the lake is narrow compared to length and in many places there is a rapid descent from the beach to deep water.

Several small streams flow into the lake and, as the lands drained by these streams are to a large extent in cultivation, it results that considerable sediments in the form of sands and muds are brought to the lake and the effects of these sediments may be expected to show in the deposits over its bottom. Also, as the lake is fairly large, there is considerable erosion of the shores and, as these are mainly composed of sandstones and glacial drift, much sand and some mud are carried outward from the shores to deeper bottoms. The waters which enter the lake through the streams and springs drain through rocks which are either dolomitic limestones or contain dolomite as a cement. As a consequence, the lake waters contain much calcium and magnesium carbonates in solution and are "hard."

Much of the shore of the lake is cliffed and some cliffs, as at Lucas Bluff, are between 50 and 100 feet high. At many places where cliffs are present there is a rapid descent into deep water. Low shores margin the southwestern end of the lake, the northeastern end, and the northwest shore from Dartford Bay to Pigeon Cove and at the head of Norwegian Bay.

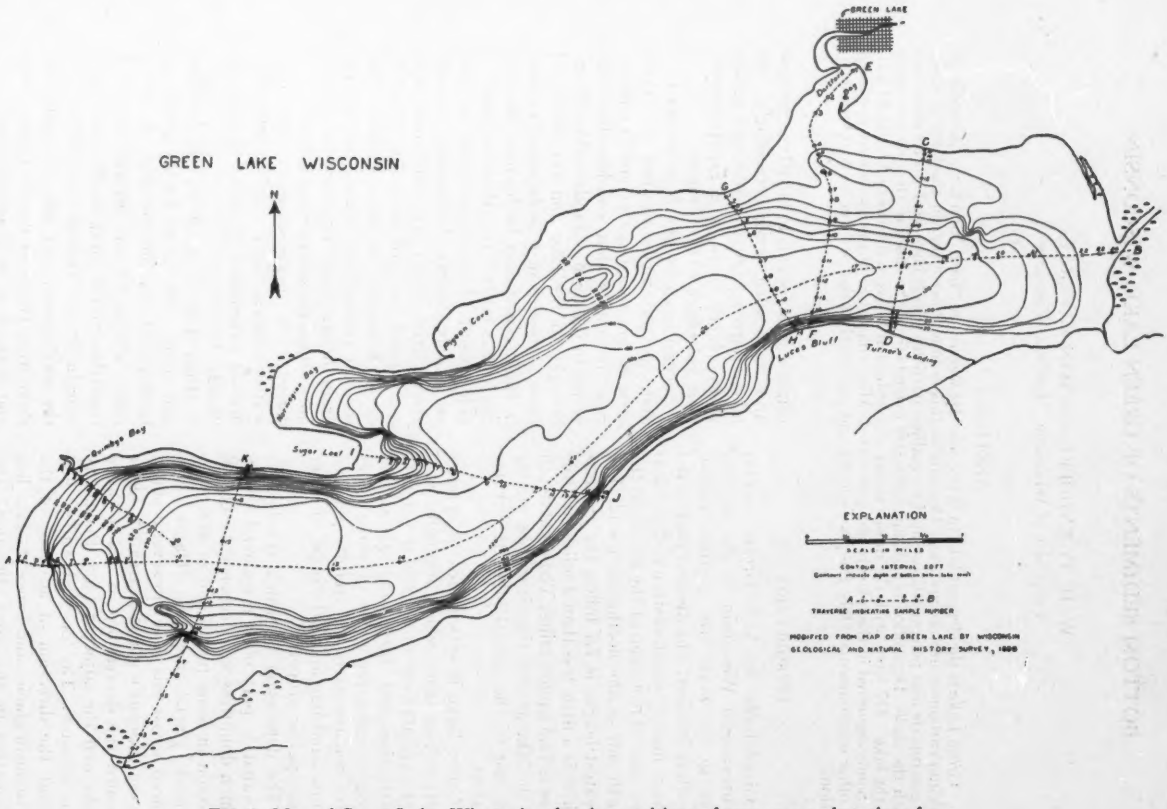

FIG. 1. Map of Green Lake, Wisconsin, showing positions of traverses and stations from which samples of the bottom sediments were taken.

MATERIALS OF THE SHORES AND COMPOSITION OF THE LAKE WATER

The materials composing the shores and underlying the surrounding areas are dolomitic limestones, sandstones, and glacial drift. The limestones belong to the Prairie du Chien formation (Lower Ordovician). The sandstones are mostly of Upper Cambrian age, but the St. Peter sandstone (Ordovician) is exposed on the northeastern shore. The top bedrocks are mainly the Prairie du Chien dolomitic limestones. These form the summits of Lucas Bluff and Sugar Loaf. The St. Peter sandstone contains beds with well rounded spherical grains of which many have frosted surfaces. Sand grains of the Cambrian sandstones are generally well rounded, some beds have angular grains, and few grains have frosted surfaces. The sandstones of the Cambrian Franconia formation contain glauconite and particles of this mineral have been found in sands collected on some beaches and places on the bottom.

Samples of water collected at several depths in Green lake on September 14, 1907 (Birge and Juday, 1911), among several other substances showed silica, calcium, magnesium, and HCO_3 as given below.

Depth of water in meters	Parts per million			
	SiO_2	Ca	Mg.	HCO_3
0	8.4	16.4	25.9	87
15	8.4	23.8	26.0	109
40	10.3	24.0	—	110
65	10.4	21.7	25.3	112

The analyses show that the quantity of magnesium in solution exceeds that required to form dolomite. Both the calcium and magnesium were derived very largely from the dolomitic limestones of the Prairie du Chien formation in which the ratio of calcium carbonate to magnesium carbonate approximates 54 to 46. As calcium carbonate is more insoluble than magnesium carbonate, it is more likely to be precipitated. It is also used by the numerous gastropods and pelecypods dwelling in the lake whereas magnesium carbonate is avoided. Thus, magnesium carbonate tends to remain in solution and ultimately to leave the lake by way of the outlet. If the lake had no outlet, the water would doubtless become saturated with magnesium carbonate and magnesite would be precipitated.

COLLECTION OF SAMPLES AND DESCRIPTION OF SEDIMENTS

The samples collected from the bottom of Green Lake were taken by the junior author during the latter part of the summer of 1942. An Ekman clam shell dredge was used and collecting was done on the seven traverses shown on Figure 1. Samples were taken at short distances apart close to the shores and at long distances over the deep bottom. Table 1 gives the depths of the bottom where samples were taken, brief descriptions of the wet samples and the percentage of calcium carbonate in each sample. Most samples have lighter colors when dry than when wet. For example, a wet sample may have a dark gray color, but the dry sample is light gray. Determinations of calcium carbonate were made by the senior writer by the method of loss of carbon dioxide on treatment with hydrochloric acid. There is great variation in the content of calcium carbonate. This variation depends on the presence of other sediments and the depths of water most favorable for the organisms and processes which precipitate the compound. It also probably depends on transportation of precipitated calcium carbonate from one place to another. Figure 2 gives profiles of the bottom along the traverses of sampling. Beneath each profile is a curve showing the distribution of calcium carbonate in the sediments along the line of traverse. The depths of greatest percentages on every traverse are between 12 and 30 feet and percentages decrease both in the direction of the shores and deep water.

Calcium carbonate sediments in the lake are of two kinds. One kind consists of entire and fragmentary shells and the

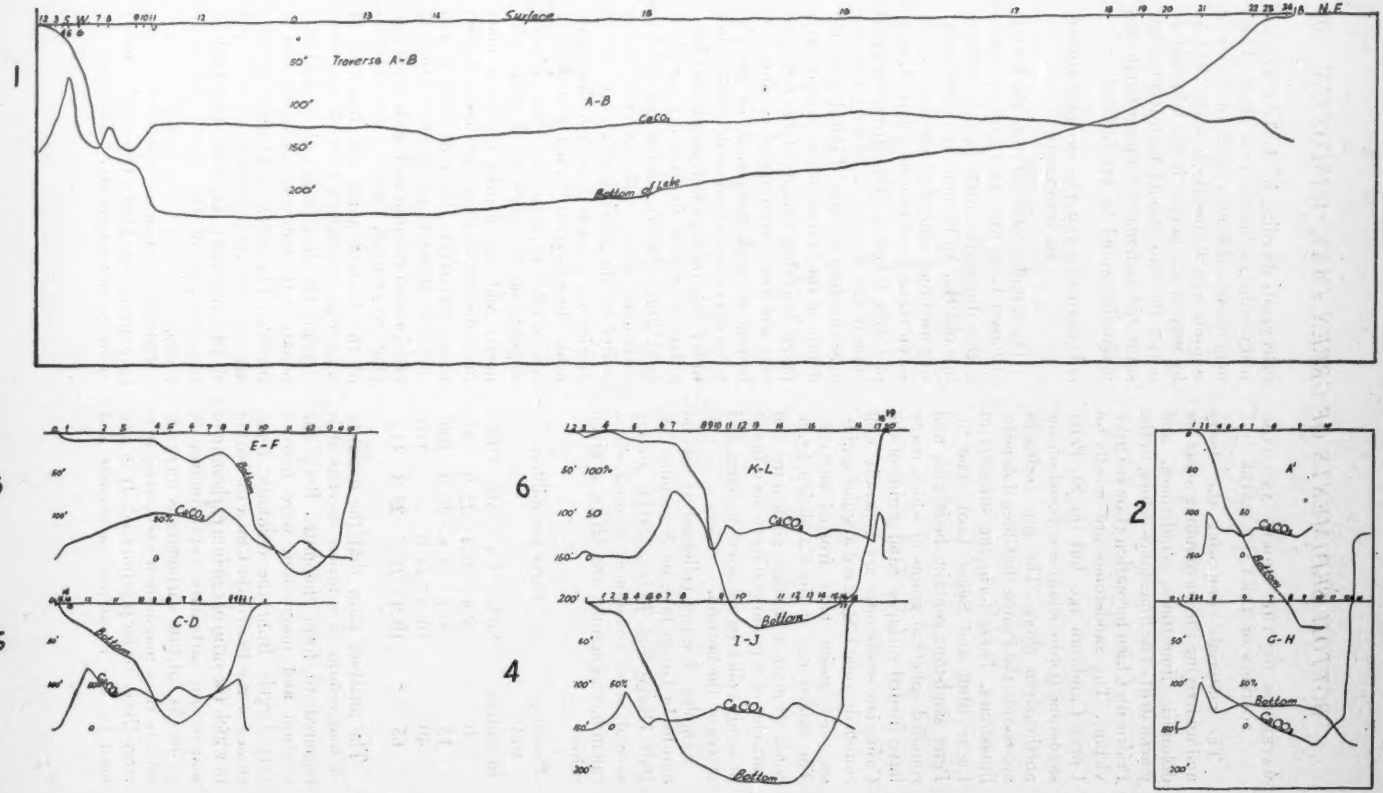
1
Surface
N.E
50'
Traverse A-B
100'
150'
200'
A-B
CaCO3
Bottom of Lake
3
E-F
Bottom
CaCO3
50%
5
C-D
Bottom
CaCO3
6
K-L
100%
50
CaCO3
4
I-J
Bottom
50%
CaCO3
Bottom
2
K'
50
CaCO3
Bottom
G-H
50%
Bottom
CaCO3

FIG. 2.

other of minute crystalline particles which seem to bear no relation to shells. Deposits of shells are confined to shallow depths; those composed of minute particles have rather general distribution over the bottom. The greatest percentages of calcium carbonate are in the deposits containing many shells. Shells are mainly those of gastropods of which one form is coiled in one plane and belongs to the genus *Helisoma*, the other shell is spiral and about as high as wide. There are at least two pelecypods of which one is up to 3 inches long and the other is not over 1 inch long. Less than half of most samples is composed of calcium carbonate. It is very probable that the percentages of calcium carbonate were higher when the areas about the lake were wooded and the inflowing streams were not able to acquire much inorganic sediment. Deposits of calcium carbonate extend to the greatest depths of the lake.

In addition to calcium carbonate, the sediments contain much clay and silt, the former composed of clay minerals, the latter mostly of finely divided quartz. Sands are common in shallow water, but they are also present over the deep bottom. Most samples contain some plant materials, but not a single sample was collected to which the term gyttja could be even remotely applied. In this respect the sediments of Green Lake are decidedly different from the sediments which are characteristics of the "soft" water lakes of the woodland region of northern Wisconsin. These lakes have a pale yellow organic gel as the most abundant component of the fine-grained sediments. Nothing of this nature was found in the deposits on the bottom of Green Lake, nor was it found in the sediments of Mendota and Monona, two "hard" water lakes near Madison, Wisconsin. Green Lake may have had deposits of gyttja in pre-cultivation days, but nothing of this nature now seems to be present.

Small nodules of sand cemented with hydrous iron oxide are present in many samples. The quantity of iron oxide is small. These nodules have been collected from depths of 135 to over 200 feet.

Sands form some of the beaches and extend outward therefrom for distances inversely correlated with depth of water. There are places on the deep bottom where the sediments consist of sands as at A-B 7, 8, 9, and 10. These are on bottoms 135 to 193 feet deep. It is somewhat difficult to understand how the sands arrived at these depths. They lie on the top of a ridge on the bottom which has deep holes on each side. This condition favors removal of fine sediments to the holes and retention of sands on the high places, but does not explain how the sands arrived on the ridges. Mechanical analyses of sands are given in Table 2. Table 3 gives

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FIG. 2. Profiles of bottom on the several traverses and curves showing content of calcium carbonate in the sediments.

1. Profile of bottom on traverse A–B. Length of traverse about 7.7 miles. Lower curve shows content of calcium carbonate on traverse.
2. Profile of bottom on traverse A′. Length of traverse about 0.8 mile. Note rise in percentage of calcium carbonate at depth of 15 feet and decrease with increase of depth of water.
3. Profile of bottom on traverse E–F. Length of traverse about 1.7 miles. As there is no shallow water on the south end of the traverse, there is a low content of calcium carbonate in the sediments. On the north end the peaks of calcium carbonate are at 11 and 27 feet.
4. Profile of the bottom on traverse I–J. Length of traverse about 1.7 miles. The content of calcium carbonate is high over the east end of the traverse in water that does not exceed 35 feet. Note rise in percentage over the high place of station 8.
5. Profile of bottom on traverse C–D. Length of traverse about 2.2 miles. On this traverse shallow water extends outward from both shores and peaks of content of calcium carbonate are present on both sides of the traverse at stations 3 and 12 in depths of water of 13 and 12 feet.
6. Profiles on bottom on traverses G–H and K–L. Length of G–H about 1 mile, of K–L about 2 miles.

the three quartiles and coefficients of sorting and skewness.

Few of the sands are well sorted and many are more poorly sorted than the coefficients of sorting indicate. A-B 23 and K-L 4 are the only well sorted sands of all collected. Several samples are moderately well sorted. The coefficients of sorting do not give a true picture in that 8 of the 28 samples contain fairly large percentages in the >2 mm. grade with distribution to the <1/16 mm. grade. These extremes do not show in the coefficients of sorting. Most sands contain very fine materials of which much is finely divided calcium carbonate. Most coefficients of sorting are in the range of 1.30 to 1.70. K-L 9 and 10 exceed 1.70 and A-B 23 and K-L 4 are less than 1.30.

The St. Peter and Upper Cambrian sandstones are the sources of most of the sands and in the beds of these formations the sands are fairly well sorted, but in Green Lake the sands from many beds are mixed together as the sandstones are eroded. Some sands are also acquired

TABLE 1. *Traverses across Green Lake, showing depths of water of places where samples were taken and giving descriptions of sediments when taken and percentages of calcium carbonates. Places of traverses are shown on figure 1.*

Traverse A-B from the southwestern to the northeastern end of the lake.

No.	Depth in feet	Description of sediment	Per Cent $CaCO_3$
1	Beach at water level	Gray sand with a few pebbles.	
2	5	Gray and brown sand, the latter on the surface, a few shells, scattered plants shoreward.	
3	12	Dark-gray mud with many shell fragments, a few entire shells, a few plants.	36
4	13	Dark-gray mud, many broken and entire shells, shells most abundant below surface, few plants.	56
5	19	Gray shell marl, mostly entire shells, and mostly gastropods.	86
6	74	Dark gray mud, containing some shells, some hard brown clay in which are many burrows.	20
7	135	Fine grayish-brown sand containing small iron oxide concretions, a few shells, bottom difficult to sample with Ekman dredge.	2
8	154	Grayish-brown mud with brown sand, and some hard clay containing burrows, small iron oxide concretions.	30
9	165	Dark-gray with mud. Many small iron oxide concretions. Shells and sand grains are coated with iron oxide.	
10	193	Dark-gray sand, contains small iron concretions and a few shells.	
11	215	Dark grayish-brown and overlying light-gray mud. Some shells with iron oxide coating.	33
12	225	Very dark gray mud, not much organic matter. Mud brown on top, no shells.	33
13	225	Mottled gray, brown and black mud.	29
14	225	Dark grayish-brown mud.	13
15	206	Dark gray mud.	30
16	175	Brown and light gray mud, some shells.	40
17	150	Silty and sandy mud of brownish-gray color, not much sand.	29
18	123	Grayish-brown silty and fine sandy mud.	22
19	104	Dark gray mud.	27
20	93	Dark gray mud.	44
21	68	Gray and brown sand with fragments of shells.	25
22	18	Dark gray sandy mud with fragments of shells, shells most abundant about 3 inches below surface of bottom.	28
23	6	Gray sand with some shell fragments.	
24	3	Gray sand with some shell fragments.	

TABLE 1—*Continued*

Traverse A[1] from Quimby's Bay to intersection with traverse A-B

No.	Depth in feet	Description of sediment	Per Cent $CaCO_3$
1	Beach	White sand.	
2	6	Gray and brown sand with plant matter and large clams.	
3	15	Light gray shell marl, many shells, same plants.	64
4	65	Light gray muddy marl.	33
5	97	Muddy gray shell marl.	33
6	126	Gray mud with shells.	25
7	157	Grayish-brown mud.	35
8	183	Brown mud overlying light gray mud, a few shells.	32
9	227	Dark gray mud.	24
10	232	Dark gray mud.	36
		Traverse K-L across the west end of the lake as shown on fig. 1.	
1	0.5	Brown and gray sand with cobbles.	
2	3	Dirty gray sand with plants.	
3	7	Gray muddy sand with many shells and plants.	10
4	3 (Bar)	Gray and brown sand with plants.	
5	11	Gray sand and mud with shells.	2
6	13	Gray shell marl.	41
7	16	Gray shell marl.	79
8	63	Gray shell marl.	46
9	115	Grayish-brown sand with small iron oxide concretions and some shells.	12
10	153	Gray silty and sandy mud with small iron concretions and shells.	10
11	204	Gray mud which is brown on top, contains shells.	40
12	220	Gray mud which is brown on top, contains shells.	31
13	232	Dark gray mud.	
14	228	Dark gray mud.	40
15	223	Dark gray mud.	27
16	190	Brown mud on gray mud.	33
17	60	Yellowish-gray mud with a few shells.	20
18	15	Gray shell marl with plants.	55
19	6	Dark-gray sand with a few shells.	
20		Gravel and sand.	
		Traverse I-J from the peninsula of Sugar Loaf directly east to the opposite shore.	
1	12	Dark gray sand and gravel.	
2	13	Dark gray sand with gravel and large clams.	13
3	21	Dark gray shell marl on top of light gray shell marl, contains plant remains.	44
4	54	Gray shell marl on top of silt in which are few shells.	26
5	83	Dark gray mud with iron oxide on shells.	7
6	102	Iron oxide crust on top of dark gray firm clay.	12
7	140	Iron oxide crust on top of dark gray firm clay.	12
8	175	Gray mud with iron concretions and a little sand.	10
9	201	Light gray mud with a little brown mud on top. Contains iron concretions and a few shells.	26
10	208	Gray mud.	22
11	212	Gray mud.	13
12	210	Gray mud.	31
13	195	Brown mud on top of gray mud, many small shells, a few large shells, a few small iron oxide concretions.	23
14	175	Brown sandy mud with shells.	
15	103	Brown sandy mud and shells.	13
16	85	Brown sandy mud and shells.	9
17	75	Cobbles and pebbles, green algae, a few shells, cobbles and pebbles with black coatings.	
18	6	Dark gray sand, brown on top, plants and large clams.	

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TABLE 1—*Continued*

Traverse G-H from north shore to Lucas Bluff

No.	Depth in feet	Description of sediment	Per Cent $CaCO_3$
1	5	Brown sand on gray sand, a few plants.	
2	11	Gray sand with a few shells and plants.	
3	19	Gray sand on light gray marly sand.	
4	26	Friable gray marl with many shells.	67
5	100	Brown and gray mud which contains a little sand about 3 inches below the surface.	21
6	125	Gray marl with occasional shells.	30
7	145	Light to dark gray and brown mud, no shells.	26
8	155	Light to dark gray mud, brown on top, vew few shells.	29
9	161	Light to dark gray mud, brown on top, no shells.	25
10	167	Light gray mud, brown on top, contains a few shells.	23
11	150	Dark gray mud, brown on top, contains broken shells.	10
12	85	Brown mud overlying an organic layer which overlies marly sand. Sample contains leaves and sticks.	
13	5	Brown sand on dark gray sand, contains plant matter.	
14		Shore, boulders, very steep bank.	
		Traverse E-F from Dartford Bay to Lucas Bluff	
1	3	Black silt with much organic matter and a few shells.	16
2	7	Friable gray sandy mud, no shells.	34
3	7	Gray sandy mud with many plants.	43
4	11	Friable gray shell marl, much plant matter.	54
5	23	Shell marl.	52
6	35	Gray mud, no shells.	49
7	30	Gray mud, with many shells.	44
8	27	Shell marl, contains a thin layer of clay.	58
9	63	Gray muddy shell marl.	36
10	115	Dark gray mud, no shells.	22
11	158	Yellowish silty mud, a few shells.	4
12	165	Gray silty mud with minute shell fragments, brown on top.	21
13	150	Brown sandy mud, no shells.	2
14	133	Brown sand with shells.	
15	57	Brown sand and mud, contains leaves, wood and a few shells.	3
		Traverse C–D. From Turner's Landing on the south shore to north shore nearly directly opposite.	
1	Beach	Gravel.	
2	5	Dark gray fine sand and mud, contains shells and plants.	21
3	13	Gray shell marl, contains plant matter.	60
4	60	Gray muddy marl, no shells.	53
5	90	Gray mud, few shells.	50
6	130	Dark gray mud, born on top.	35
7	143	Dark gray mud.	50
8	133	Dark gray mud.	33
9	110	Dark gray mud.	39
10	73	Dark gray mud with shells 3 inches below surface of mud.	50
11	55	Dark gray marly mud, with few shells.	41
12	34	Dark gray shell marl.	73
13	18	Gray marly sand with shells.	
14	6	Gray sand, no shells, sand brown on top.	
15	Beach	Gravel.	

from glacial deposits. Thus, any sample may contain sands from all of the sources. If the sands had been subjected to extensive washing and transportation, as would have been the case on a sea beach, or had they been transported by the wind, the different size grades would have been separated and good sorting would have been made. Most samples collected in Green Lake have 75 per cent in the ½ to ¼, ¼ to ⅛, and ⅛ to 1 mm. grades. Exceptions are K-L 9, 10, and 20 and I-J 1 and 2 in all of which a large percentage is in the >2 mm. grade.

Coefficients of skewness are rather closely bunched in the range of 0.90 to 1.10. Only A-B 10 and K-L 2 have coefficients less than 0.90 and only K-L 10 and G-H 1 have coefficients greater than 1.10.

Most of the sand grains are well rounded, many are highly spherical, and every sample contains many grains with frosted surfaces. The highly rounded and spherical grains and those with frosted surfaces owe none of these characters to processes operating in the lake. These characters were developed under other environmental conditions and have been inherited. The angular grains of ½ mm. to higher grades are also not related to lacustrine deposition; the angularities were inherited from the sediments deposited by ice and melt waters. The only

TABLE 2. *Mechanical analyses of sands from Trout Lake.*

	<2 mm.	1–2 mm.	½–1 mm.	¼–½ mm.	⅛–¼ mm.	1/16–⅛ mm.	<1/16 mm
				A–B			
1.	15.00%	0.90%	39.65%	43.30%	0.05%	0.05%	1.05%
7.	11.50	1.23	2.10	29.55	34.68	11.07	9.87
9.		0.44	1.32	23.68	49.64	11.92	13.00
10.		0.76	1.91	43.85	32.00	5.57	15.91
23.				17.50	74.75	6.80	0.95
24.		1.85	1.80	23.35	54.70	16.75	1.55
				A′			
1.	2.30	2.70	25.75	68.60	0.50	0.15	0.00
2.	1.85	0.20	1.45	30.40	49.35	12.25	4.50
				K–L			
1.	8.60	1.50	17.05	63.20	7.70	1.25	0.70
2.	0.35	0.10	6.75	59.25	27.65	3.85	2.05
3.		3.90	8.60	35.95	28.85	11.90	10.80
4.	0.50	0.90	10.40	70.00	11.10	2.15	4.95
5.	2.10	1.80	4.50	18.70	36.80	31.05	5.05
9.	20.50	1.10	1.85	26.15	25.80	11.40	13.20
10.	16.05	4.30	2.70	20.40	30.20	12.65	13.70
19.	0.45	0.90	3.10	34.50	50.75	8.20	2.10
20.	67.76	1.49	5.82	19.36	5.01	0.45	0.11
				I–J			
1.	38.09	1.49	4.30	27.96	18.95	6.34	2.87
2.	27.15	0.98	6.58	32.32	21.62	7.65	3.70
18.	1.40	4.65	7.40	37.05	32.60	11.80	5.10
				G–H			
1.		0.75	4.40	40.20	47.70	5.90	1.05
2.			1.40	53.30	36.90	5.15	3.25
3.		1.60	6.15	61.25	27.85	1.55	1.60
13.	1.05	0.80	3.15	43.70	39.50	11.40	0.40
				E–F			
14.			0.80	11.60	32.00	36.50	19.10
				C–D			
13.	3.93	1.50	4.67	64.18	24.68	0.64	0.40
14.		0.65	2.15	29.05	62.60	4.70	0.85
15.		0.45	2.40	29.20	60.75	6.10	1.10

TABLE 3. *First, second (Median) and third quartiles and coefficients of sorting and skewness of the sands of Green Lake.*

	Q1	Q2	Q3	So	Sk
			A–B		
1.	71/80	45/80	31/80	1.53	1.08
7.	66/160	37/160	23/160	1.69	1.04
9.	41/160	30/160	20/160	1.43	0.91
10.	60/160	39/160	22/160	1.65	0.86
23.	38/160	31/160	24/160	1.26	0.95
24.	44/160	32/160	23/160	1.38	0.99
			A′		
1.	48/80	34/80	27/80	1.33	1.12
2.	52/160	33/160	23/160	1.50	1.09
			K–L		
1.	46/160	33/160	25/160	1.35	1.06
2.	68/160	52/160	34/160	1.41	0.85
3.	66/160	39/160	22/160	1.73	0.95
4.	36/80	29/80	22/80	1.28	0.94
5.	88/320	54/320	33/320	1.63	0.99
9.	152/320	79/320	41/320	1.92	0.99
10.	76/160	35/160	19/160	2.00	1.17
19.	56/160	36/160	26/160	1.47	1.10
			I–J		
18.	68/160	41/160	25/160	1.65	1.01
			G–H		
1.	30/80	19/80	14/80	1.46	1.16
2.	62/160	44/160	30/160	1.43	0.96
3.	17/40	13/40	9/40	1.37	0.90
13.	62/160	39/160	27/160	1.57	1.10
			E–F		
14.	64/320	37/320	23/320	1.67	1.08
			C–D		
13.	70/170	54/160	39/160	1.34	0.93
14.	48/160	34/160	26/160	1.32	1.08
15.	48/160	33/160	25/160	1.39	1.10

characteristics due to lacustrine deposition are the rather poor degree of sorting, the common presence of calcium carbonate in the <1/16 mm. grade, and the nature of stratification.

Gravels cover some parts of the shores, but do not extend very far outward. Composition is like that found in the glacial deposits which form some parts of the shores and it is assumed that they were washed therefrom.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 15, No. 3, PP. 103–104, DECEMBER, 1945

REVIEWS

JOHNSON, J. HARLAN. 1945. *A Résumé of the Paleozoic Stratigraphy of Colorado*, Quart. Colorado School of Mines, Vol. 40, No. 3, pp. 1–109.

This work is a compilation and is of value as a work of reference and a guide to the literature on the Paleozoic stratigraphy of Colorado. Much work has gone into its preparation and a bibliography of 268 papers was consulted. The work will be of great value to those who do geologic work in Colorado and parts of neighboring states. There are 17 text figures and two correlation charts (in pocket).

REICHE, PARRY, 1945. *A Survey of Weathering Processes and Products*, University of New Mexico Publications in Geology, No. 1, pp. 1–87.

This work is of interest to students of sediments as there are described and summarized the various ways by which rocks are destroyed and sediments produced. An excellent review is presented of the various processes concerned in weathering and the products resulting from the operation of these processes. Opinion is expressed as to the importance of the different processes. The book contains five chapters of which the headings are as follows: Physical Processes, Chemical Processes and Reagents, Results of Chemical Weathering, Soil-forming Processes and Soils, and Factors of Relief and Time.

Reiche concludes that the essentially physical weathering processes are of secondary importance and that only unloading and crystal growth, including frost action, are significant. The writer does not entirely agree with this conclusion. Chemical weathering is considered extremely important and end products "are those alteration products which have high measure of stability in the near-surface zone" of which the most abundant are clay minerals and hydrous aluminum and iron oxides. Under certain climatic conditions even the clay minerals are broken down and changed to hydrous oxides. The chapter on the formation of soil emphasizes the influence of climate, relief, and time, but minimized the importance of the parent material. The reviewer does not concur in the latter part of this statement. Formation of the several varieties of soil are described and the processes responsible for the variations are considered. There is a bibliography of 67 papers.

Problems in Geology and Geophysics. 1945. Daly Volume, *Am. Jour. Sci.*, Vol. 243-A, pp. i–xvi, 1–541.

This volume was prepared as a tribute to Professor Reginald Aldworth Daly by his colleagues, friends, and former students on his retirement at the age of 70 years on May 19, 1942. The volume contains 26 articles. Twenty-seven articles were planned but one intended contributor, Doctor Robert W. Sayles, died during the preparation of his contribution to the volume. The first article, Strategy in Geology, consists of excerpts from Professor Daly's writing.

The different articles cover a considerable field of geology but a field not as expansive as that of Professor Daly's interest. This ranged over the entire field of geology and he has made contributions to most of them, only paleontology seems to have been omitted from his research. The papers emphasize igneous and mining geology, character of the earth's interior, and diastrophism. There is one paper on glacial geology by Antevs and perhaps the paper planned to be prepared by Doctor Sayles, Further Studies in Bermuda, might have given some attention to geomorphology. Papers dealing with geomorphology, stratigraphy, and sedimentation, in which divisions of geology Professor Daly had a keen interest, are not present in the volume.

This volume will be of interest to many geologists, either because some

papers deal with the fields of their interest or because of the strong friendship that many geologists have for Professor Daly, but sedimentationists, geomorphologists, stratigraphers, sedimentary petrographers, and petroleum geologists will find little or nothing in the volume bearing on their work.

ANNOUNCEMENT

NOTE FROM THE EDITOR OF THE *JOURNAL OF SEDIMENTARY PETROLOGY* TO MEMBERS OF THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS AND OTHERS WHO MAY BE INTERESTED IN THE *JOURNAL*

During the war period the *Journal of Sedimentary Petrology* has managed to continue publication by reason of accumulation of manuscripts accepted before the war. With the entrance of the United States into the war the number of contributions dropped to about 25 per cent of the number previously sent to the Editor. Few members of the Society of Economic Paleontologists and Mineralogists have made contributions and most of the associate editors of the *Journal* were occupied with war duties. The result has been that the pre-war accumulations of manuscripts have been published and the *Journal* is now in dire need of contribution of manuscripts from the members of the Society and from others who are interested in or subscribers to the *Journal*. No blame can be attached to any one because of the situation that has developed. The editor realizes that everyone has been giving his or her attention to the war effort and the time was not available for much research not connected with that effort. As the war has been brought to a successful conclusion, more time will be available for research and there doubtless was an accumulation of data prior to the war which now can be prepared for publication. Preparation of manuscripts should be started at once and unfinished manuscripts should be brought to completion. Please send contributions as early as possible to the Editor of the *Journal of Sedimentary Petrology*, Room 208 Science Hall, Madison 6, Wisconsin.

W. H. TWENHOFEL, *Editor*
Journal of Sedimentary Petrology

Journal

of

Sedimentary Petrology

VOLUME 15

APRIL, 1945-DECEMBER, 1945

Nos. 1-3

W. H. TWENHOFEL, EDITOR

PUBLISHED BY THE

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

A DIVISION OF

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Box 979, Tulsa, Oklahoma

Journal of Sedimentary Petrology

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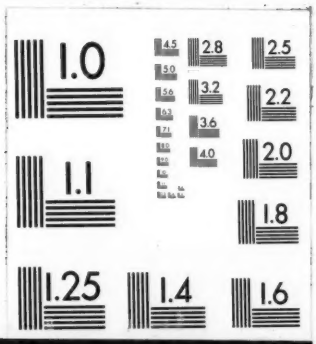
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